SAMPLING DEEP ORE DEPOSITS BY ROTARY DRILLING AND METHODS OF SURVEYING AND CONTROLLING THE DIRECTION OF DRILL HOLES

BY RUSSELL R. TRENGOVE AND A. C. JOHNSON

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Information Circular 7768

UNITED STATES DEPARTMENT OF THE INTERIOR
Fred A. Seaton, Secretary
BUREAU OF MINES
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Work on manuscript completed December 1954. The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is made: "Reprinted from Bureau of Mines Information Circular 7768."

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by

Russell R. Trengove[1/] and A. C. Johnson[2/]

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SUMMARY

Core samples from an ore horizon 2,000 feet below the surface were successfully obtained by rotary drilling at the property of the Eureka Corp., Eureka, Nev. The ore was soft and friable; cores were not obtained previously with diamond drills.

Whipstocking was used to get samples in a zone 200 feet from a vertical hole. A technique in shipstocking, by which the direction and deviation of the holes were controlled by means of nonfriction-type survey instruments, was successfully employed.

INTRODUCTION

The geology of the Eureka, Nev., district has been fully described by Hague[3/] and Curtis.[4/] Walcott[5/] and Resser[6/] wrote several reports covering the fauna found in the Cambrian formation, in which virtually all the ore deposits occur. Through the work of Wheeler and Lemmon,[7/] a stratigraphic sequence with accurately measured strata was established.

The oxide and sulfide ore bodies occur as typical replacement deposits in the El Dorado dolomite, a member of the Paleozoic sedimentary formations that are widespread through the Great Basin area.

The ore bodies discovered and mined at Ruby Hill seem to have no definite pattern as to position, size, or shape. The physical condition of the dolomite and the main structural features, the Ruby Hill and other faults, are the most important factors in formation and distribution of the ore bodies.

The large production of ore from the Ruby Hill mines has come from the upper ore segment of the Ruby Hill fault. This segment was a wedge-shaped mass with a maximum width of 1,200 feet and a length of 4,000 feet on the surface. It rests

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3/ Hague, Arnold, Abstract of the Report on the Geology of the Eureka District, Nev.: In 3d Ann. Rept., Geol. Survey, 1881-82, 1833, pp. 237-290; also Geology of the Eureka District (Nev.): Geol. Survey Mon. 20, 1892, p. 419.

4/ Curtis, J. S., Silver-Lead Deposits of Eureka, Nev.: Geol. Survey Mon. 7, 1884, p. 200.

5/ Walcott, D. D., Paleontology of Eureka District, Nev.: Geol. Survey Mon. 8, 1884, p. 298.

6/ Resser, C. E., Nomenclature of Some Cambrian Trilobites: Smithsonian Misc. Coll., vol. 93, No. 5, 1935, p. 46. Second Contribution to Nomenclature of Some Cambrian Trilobites: Smithsonian Misc. Coll., vol. 95, No. 4, 1936, pp. 1-29. Third Contribution to Nomenclature of Some Cambrian Trilobites: Smithsonian Misc. Coll., vol. 95, No. 22, 1937, pp. 1-29.

7/ Wheeler, Harry E., and Lemmon, Dwight M., Cambrian Formations of the Eureka and Pioche Districts, Nev.: Geol. and Min. Survey, No. 31, vol. 33, No. 3, 1939, pp. 13-32.

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on a footwall of Prospect Mountain quartzite, and the hanging wall is the Ruby Hill fault. All ore within the area was completely oxidized and contained high values of lead, silver and gold. The wedge tapered out at about 1,200 feet, where the Ruby fault cut the underlying quartzite.

Geologic conditions indicated possibilities of finding large ore bodies at higher elevations than those found by diamond drilling in the down-faulted section. If ore was found at a higher horizon it would permit bringing the mine into production at a lower cost than that required to unwater the 2,250-foot level. A program of exploration, by rotary drilling, to test areas above the down-faulted section was begun in 1950. Rotary drilling was selected in preference to diamond drilling because the latter had not been successful in obtaining core during the previous exploration program.

Four deep holes were rotary-drilled to explore a section northeast of the Ruby Hill fault and northwest of the Bowman fault to a depth of about 2,000 feet below the surface. This area was selected and drilled on a line more or less parallel to the Ruby Hill fault, extending northwest from the Bowman fault. The holes explored a favorable horizon 500 or 600 feet higher than the ore found in the Fad shaft section.

A close check of the bearing and inclination of each drill hole was maintained by using directional surveying instruments. Previous drilling by the Eureka Corp. had shown that the holes tended to deflect toward the fault. One hole was whipstocked into line several times because it tended to turn toward the fault. Only four holes were drilled in the higher Eldorado dolomite. No ore was found in these holes.

The previous diamond-drilling program by the Bureau of Mines and the operating company was successful in locating the extensions of the ore bodies in the down-faulted section. This drilling was done from the 900-foot level of the Locan shaft. The lengths of the holes drilled were 1,433 to 1,582 feet. No core samples were obtained from the main ore body owing to the friability and softness of the ore. The estimate of the quantity and grade of ore reserves was based on analyses of the sludge samples.

Eureka Corp., Ltd., sank the Fad shaft[8/] 2,415 feet to make the ore available for exploitation. A crosscut on the 2,250-foot level encountered a great flow of water about 700 feet from the ore body that flooded the shaft. Pumping up to 9,000 gallons a minute failed to recover the 2,250-foot level.

ACKNOWLEDGMENTS

The authors thank George W. Mitchell, General Manager, Eureka Corp., Ltd., for rendering valuable assistance in collecting the data on surveying a directionally drilled rotary hole and for permission to publish the collected information. Special acknowledgment is due H. Douglas Lemons, Directional Drilling Supervisor, Long Beach, Calif., for explaining and demonstrating the deflection procedure and directional surveying herein described. Thanks are due also to James K. Story, Chief Engineer, V. E. Kuster Co., Inc., Long Beach, Calif., for furnishing the illustrations from his company's publication "HKE-28-2 - The HK Single-Shot Survey Instrument and Its Operation," which are reproduced in this information circular.

8/ Mitchell, George W., and Johnson, A. C., Shaft-Sinking Methods and Costs and Cost of Plant and Equipment at the Fad Shaft, Eureka Corp., Ltd., Eureka, Nev.: Bureau of Mines Inf. Circ. 7495, 1949, pp. 3-6.

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ROTARY-DRILLING EQUIPMENT USED

The Sierra Drilling Co., Bakersfield, Calif., contracted to drill the rotary holes for the Eureka Corp. Eight semitrailers were required to transport the necessary equipment from Bakersfield to the property. The equipment weighed about 160 tons. The rotary-drill rig (fig. 1), valued at $120,000., was semiportable and could be moved from one drill site to another in the immediate vicinity within 2 days. The rig had a 90-foot mast with a pipe rack and derrickman's platform 60 feet above the rig floor, so that 60-foot stands of drill pipe could be pulled out of the hole and racked vertically beside the mast. Two 200-horsepower, butane-driven engines furnished power for operating the draw works (hoisting equipment) and for turning the rotary table. A third engine furnished power for operating the mud-fluid circulating pump, which had a capacity of 400 gallons of mud fluid at 65 strokes per minute.

The equipment was designed to drill holes up to 5,000 feet in depth. Rates of drilling per 8-hour shift ranged from 5 feet in silicified dolomite to 160 feet in unsilicified dolomite formations. Average progress per shift at the Eureka Corp. property was 30 feet.

The crew consisted of a driller, who was in charge of the operations, two helpers, and a derrickman. The driller operated the hoisting and drilling equipment, and two helpers on the derrick floor operated the pipe tongs and pipe slips when running drill pipe into and out of the drill hole. A derrickman who worked on the platform 60 feet above the derrick floor clamped the pipe elevators to the drill stem when lowering a column of drill pipe and unclamped them as the drill pipe was being withdrawn.

When adding additional joints of drill pipe to the drill stem or when withdrawing the stem from the hole to replace worn bits, the Kelly was placed in a 40-foot "rathole" which had been drilled at a slight angle from the vertical about 12 feet from the drill hole.

The Eureka Corp. paid $685 a day rental for the use of the drill rig on a three-shift basis. This cost included the wages of the crews. In addition, the corporation paid for transporting the drill rig from Bakersfield, Calif., to the drill site and return and paid the cost of cement, aquagel, butane, and lubricating oil. The corporation also furnished the water needed for drilling and the electric power used for lighting the rig and drill site. The drilling crew of 4 men worked 8-hour shifts, so that 12 men were needed for continuous operations; work was continuous 7 days a week. The roller-type drilling bits were owned by the manufacturer and rented to the drilling contractor. The contractor paid $165 for 9-7/8-inch diameter bits. Worn teeth of the bits were built up from time to time at the drilling site with tungsten carbide; and, when the bearings in the core of the bits wore out, the bit was returned to the manufacturer.

DRILLING PROCEDURE

The drill column consisted of 4-1/2-inch-o.d. drill pipe weighing 14 pounds per foot. The wall thickness of the pipe was about three-eighths inch. To provide security against twistoffs and to stabilize the motion of the drill column when operated under high bit pressure and rapid rotational speed, a 6-inch-o.d. drill collar having a wall thickness of 1 inch was screwed to the bottom of the drill stem. The drilling bit was attached to the bottom of the drill column. A grief stem, or Kelly, 42 feet long was attached to the top of the drill stem. The grief stem was

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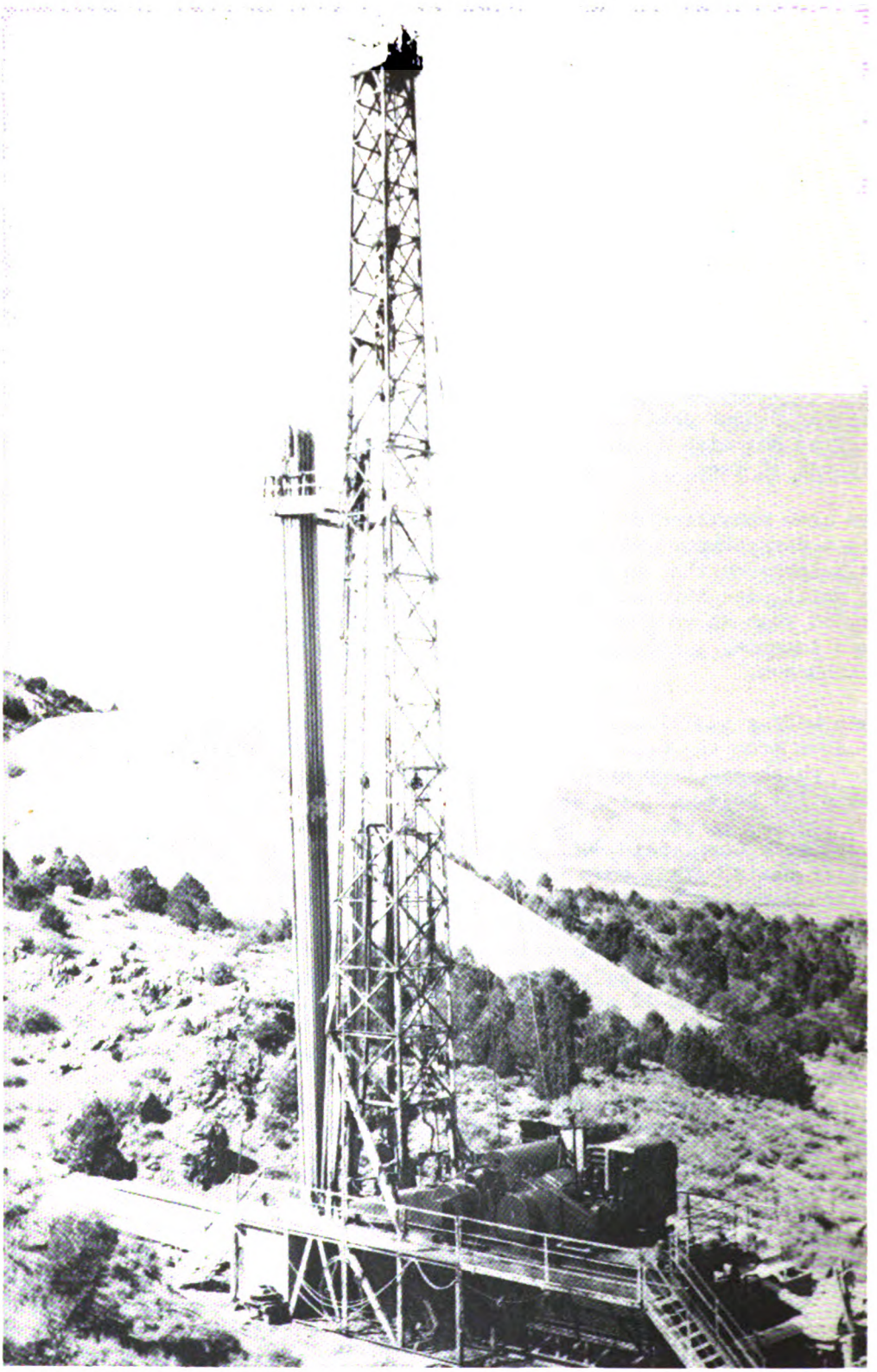

Figure 1. - Rotary drill rig.

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square in cross section and designed to fit a square opening extending through the driving bushing of the rotary table. As the rotary table was turned, the positive grip of the table on the drill column caused the drill stem and bit to revolve. The grip on the table on the grief stem was loose enough to permit the grief stem to be lowered as drilling progressed. Bit rotation usually ranged from 75 to 100 r.p.m.

Most of the drilling through nonmineralized formations was with Hughes Tricone or Reed (2-gage cutter and 2 cone) bits. In core drilling, a diamond core bit having a 6-inch outside diameter and taking 3-1/2-inch cores was used together with a 15-foot full-floating core barrel. Coring was done when information was desired on the formation and when drilling through mineralized sections.

To remove the drill cuttings from the hole, a fluid made by mixing aquagel with water in the ratio of 5 sacks of aquagel to 50 barrels of water was circulated. The viscosity of the circulating fluid was controlled by noting the time in seconds required for 1 liter of fluid to flow from a funnel with a 1/4-inch-diameter discharge; the viscosity usually was maintained so that it took about 50 seconds for this test. Mud fluids of greater viscosity were used when losses in circulation were noted.

The circulating fluid was pumped through a swivel at the top of the Kelly joint into the rotating drill column while the latter was suspended in the drill hole. Drill cuttings thus were washed from the drill hole up along the outside of the drill column. The drill cuttings and circulating fluid from the drill hole were passed over a shale shaker or vibrating screen to remove the cuttings. This shaker was provided with a 30-mesh screen through which the circulating fluid and undersize fines returned to the circulating system.

During the progress of drilling, samples of the cuttings in the circulating fluid were taken after each 5 feet drilled. These samples were passed over a small Wilfley table, where it was possible to detect showings of any minerals encountered in the drilling.

PROCEDURE FOR CONTROLLED DIRECTIONAL DRILLING

A hole may be drilled vertically or deflected from a vertically drilled hole. There usually is a saving in time and money by starting directional drilling from a determined location rather than attempting to drill a perfectly directed hole from top to bottom.

Directional drilling will produce a curved hole, the position of the bottom being checked at intervals by surveys. The most popular tool is the whipstock, shown in figure 2. This is a cylindrical chrome-steel casting with a round, concave groove in its inclined face, tapered at 3° from a collar at the upper end to the edge of the tool near the bottom. The chisel-shaped lower end, when forced into the cement plug in the hole at the point of deflection, prevents the whipstock from turning.

A hole was whipstocked from one of the holes in the series drilled. The deflection of the hole was started 978 feet below the surface. A 9-inch whipstock, using a 7-1/2 inch rathole bit, was used to deflect a 10-inch hole. Different lengths of run were made depending upon the formation drilled and the desired deflection, but usually a 12- to 15-foot rathole gave maximum results. After the rathole was drilled, the whipstock was pulled to the surface. The outside collar on the retrieving sub (fig. 2) engaged the collar on the whipstock and brought the whipstock out of the hole. A pilot reamer was then used to ream the rathole to correct size, and drilling of the deflected hole was started with a 9-7/8-inch bit. The purpose

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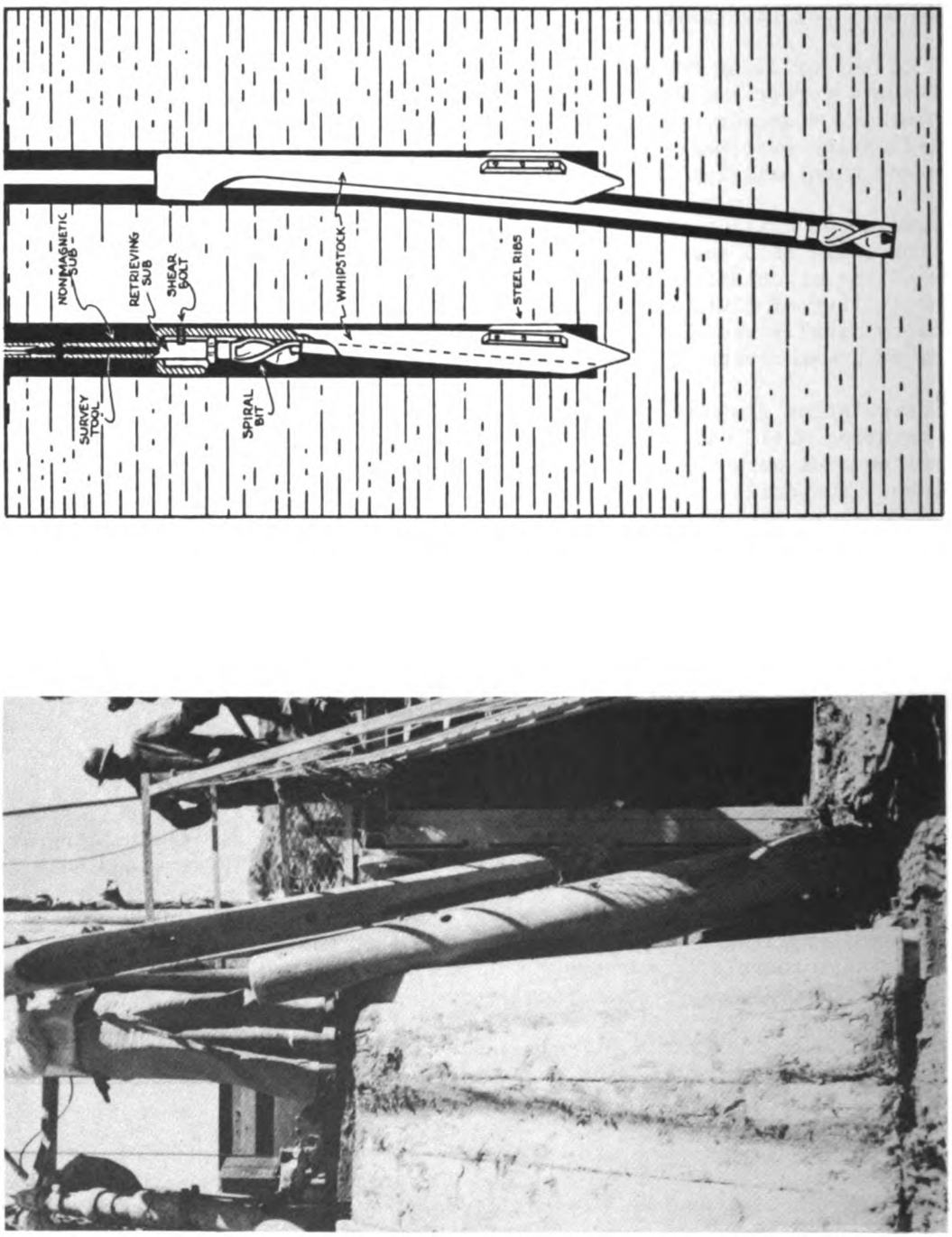

Figure 2. - The whipstock (two parts).

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of drilling the deflected hole was to obtain information 200 feet horizontally from the bottom of the vertical hole that had been drilled. Drill-hole surveying methods were used to obtain accurate bearings and dip of the hole. To reach the desired objective this hole was surveyed many times, and 10 whipstock settings were made in the 891 feet of deflected hole. The hole tended to drift south toward the nearby Ruby Hill fault.

To form a base for deflecting the hole at 978 feet below the collar, a wooden plug that served as a base for the cement was inserted in the hole. This wooden plug, a pole 8 feet long and about 8-1/2 inches in diameter, had 7/8 inch staggered holes drilled in planes at right angles to the pole at 6-inch intervals. Pieces of 7/8-inch cable 14 inches long were threaded through these holes. Three inches of cable protruded from each side of the pole, which made the wooden plug resemble an oversize bottle washer. The pole was then forced down the drill hole to a point several feet below the deflection point, where its position was maintained by friction of the ends of the cable on the wall of the drill hole. This wooden plug thus served as a base for the cement which was placed in the hole up to the starting point of desired deflection.

A whipstock was then assembled on the derrick floor. The assembly consisted of the whipstock, retrieving sub, and nonmagnetic sub and bit. The collar at the top of the whipstock was large enough to allow the drill pipe to pass through it but too small to pass the bit. The whipstock could thus be removed with the drill column when desired. In making up the whipstock assembly, the bit was screwed into the retrieving sub (fig. 2) and the free end of the sub passed through the collar of the whipstock. A K-Monel metal (nonmagnetic), high-strength, orienting collar was then made up on the free end of the retrieving sub. A 7/8-inch-diameter shear bolt passed through the collar of the whipstock into the retrieving sub, so that the whipstock could be turned by rotating the drilling string. The whipstock assembly was then lowered to the top of the cement plug in the conventional manner by adding sections of drill pipe.

When landed in the hole, the whipstock was faced in the direction in which the hole was to be deflected. This was done by using survey instruments.

The two Angle and Compass units used in the survey were the only nonfriction apparatus available for determining deviations of boreholes from the vertical and the direction of deviation. These units are described in the subsequent paragraphs.

The principle and operation of the 0° - 70° Angle and Compass unit (fig. 5) may be described as follows:

If a hollow sphere is floated in fluid it is free to rotate about any axis. If a sector is cut from the sphere and allowed to float in the fluid, the only axis about which it can rotate is one which is perpendicular to the surface of the fluid. If the sector of the sphere and its fluid are confined in a spherical cavity container (fig. 5), which has a center post with a sphere at its lower end, the sector will remain accurately centered, yet will be able to rotate about its axis. If magnets are installed in the floating sector, it will always orient itself to the magnetic field of the earth by rotating about its own axis. The container may be tilted to any position up to and including an inclination of 70° from the vertical without affecting the float, because the surface of the fluid always remains parallel to the surface of the earth.

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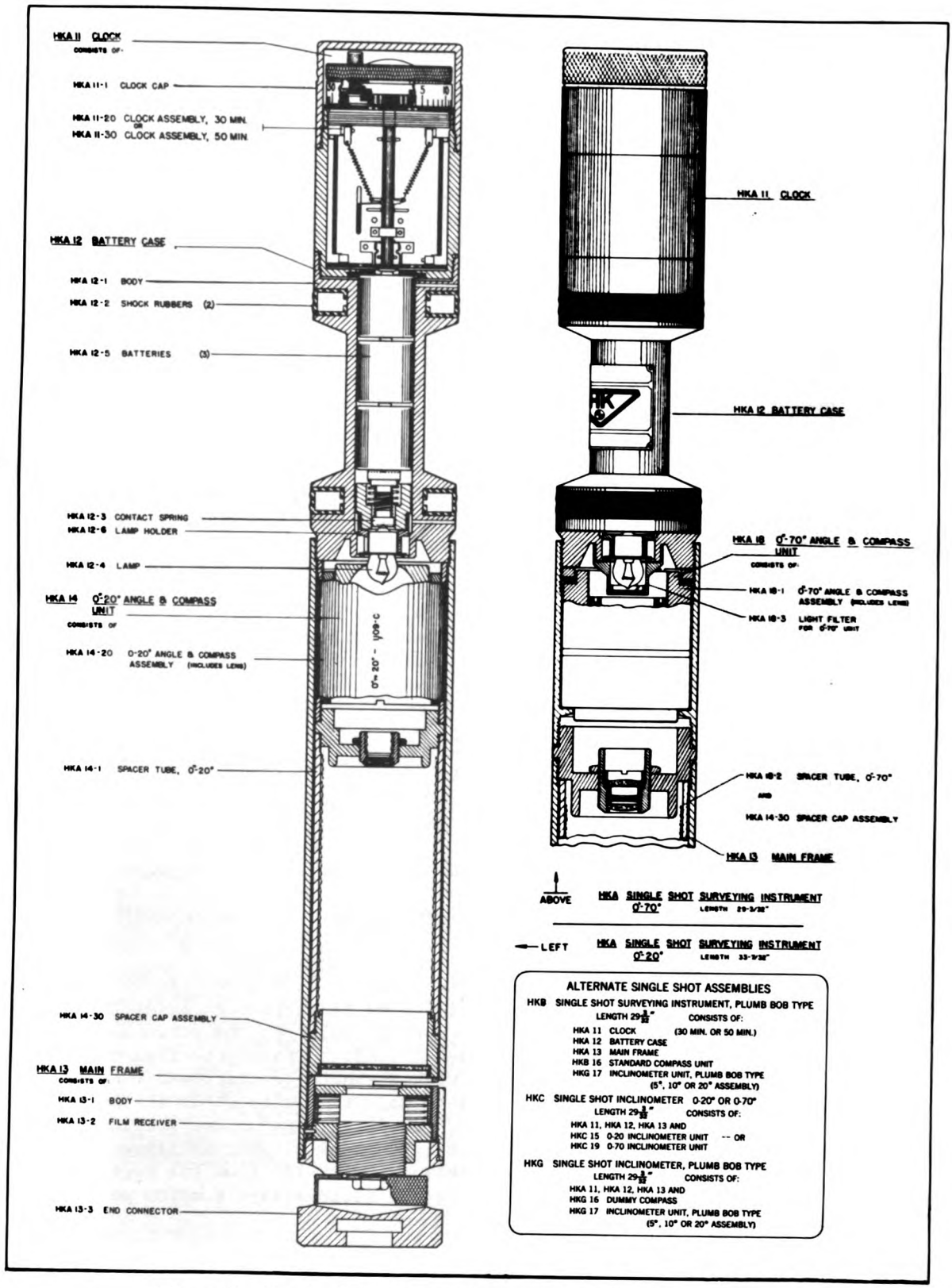
HKA 11 CLOCK
CONSISTS OF-
HKA 11-1 CLOCK CAP
HKA 11-20 CLOCK ASSEMBLY, 30 MIN.
OR
HKA 11-30 CLOCK ASSEMBLY, 50 MIN.
HKA 12 BATTERY CASE
HKA 12-1 BODY
HKA 12-2 SHOCK RUBBERS (2)
HKA 12-5 BATTERIES (3)
HKA 12-3 CONTACT SPRING
HKA 12-6 LAMP HOLDER
HKA 12-4 LAMP
HKA 14 0°-20° ANGLE & COMPASS UNIT
CONSISTS OF
HKA 14-20 0-20° ANGLE & COMPASS ASSEMBLY (INCLUDES LENS)
HKA 14-1 SPACER TUBE, 0°-20°
HKA 14-30 SPACER CAP ASSEMBLY
HKA 13 MAIN FRAME
CONSISTS OF
HKA 13-1 BODY
HKA 13-2 FILM RECEIVER
HKA 13-3 END CONNECTOR
HKA 11 CLOCK
HKA 12 BATTERY CASE
HKA 16 0°-70° ANGLE & COMPASS UNIT
CONSISTS OF-
HKA 16-1 0°-70° ANGLE & COMPASS ASSEMBLY (INCLUDES LENS)
HKA 16-3 LIGHT FILTER FOR 0°-70° UNIT
HKA 16-2 SPACER TUBE, 0°-70°
AND
HKA 14-30 SPACER CAP ASSEMBLY
HKA 13 MAIN FRAME
ABOVE HKA SINGLE SHOT SURVEYING INSTRUMENT 0°-70° LENGTH 29-3/32"
LEFT HKA SINGLE SHOT SURVEYING INSTRUMENT 0°-20° LENGTH 33-9/32"
ALTERNATE SINGLE SHOT ASSEMBLIES
HKB SINGLE SHOT SURVEYING INSTRUMENT, PLUMB BOB TYPE
LENGTH 29 3/32" CONSISTS OF:
HKA 11 CLOCK (30 MIN. OR 50 MIN.)
HKA 12 BATTERY CASE
HKA 13 MAIN FRAME
HKB 16 STANDARD COMPASS UNIT
HKG 17 INCLINOMETER UNIT, PLUMB BOB TYPE (5°, 10° OR 20° ASSEMBLY)
HKC SINGLE SHOT INCLINOMETER 0-20° OR 0-70°
LENGTH 29 3/32" CONSISTS OF:
HKA 11, HKA 12, HKA 13 AND
HKC 15 0-20 INCLINOMETER UNIT -- OR
HKC 19 0-70 INCLINOMETER UNIT
HKG SINGLE SHOT INCLINOMETER, PLUMB BOB TYPE
LENGTH 29 3/32" CONSISTS OF:
HKA 11, HKA 12, HKA 13 AND
HKG 16 DUMMY COMPASS
HKG 17 INCLINOMETER UNIT, PLUMB BOB TYPE (5°, 10° OR 20° ASSEMBLY)

Figure 3. - Single shot surveying instruments and inclinometers.

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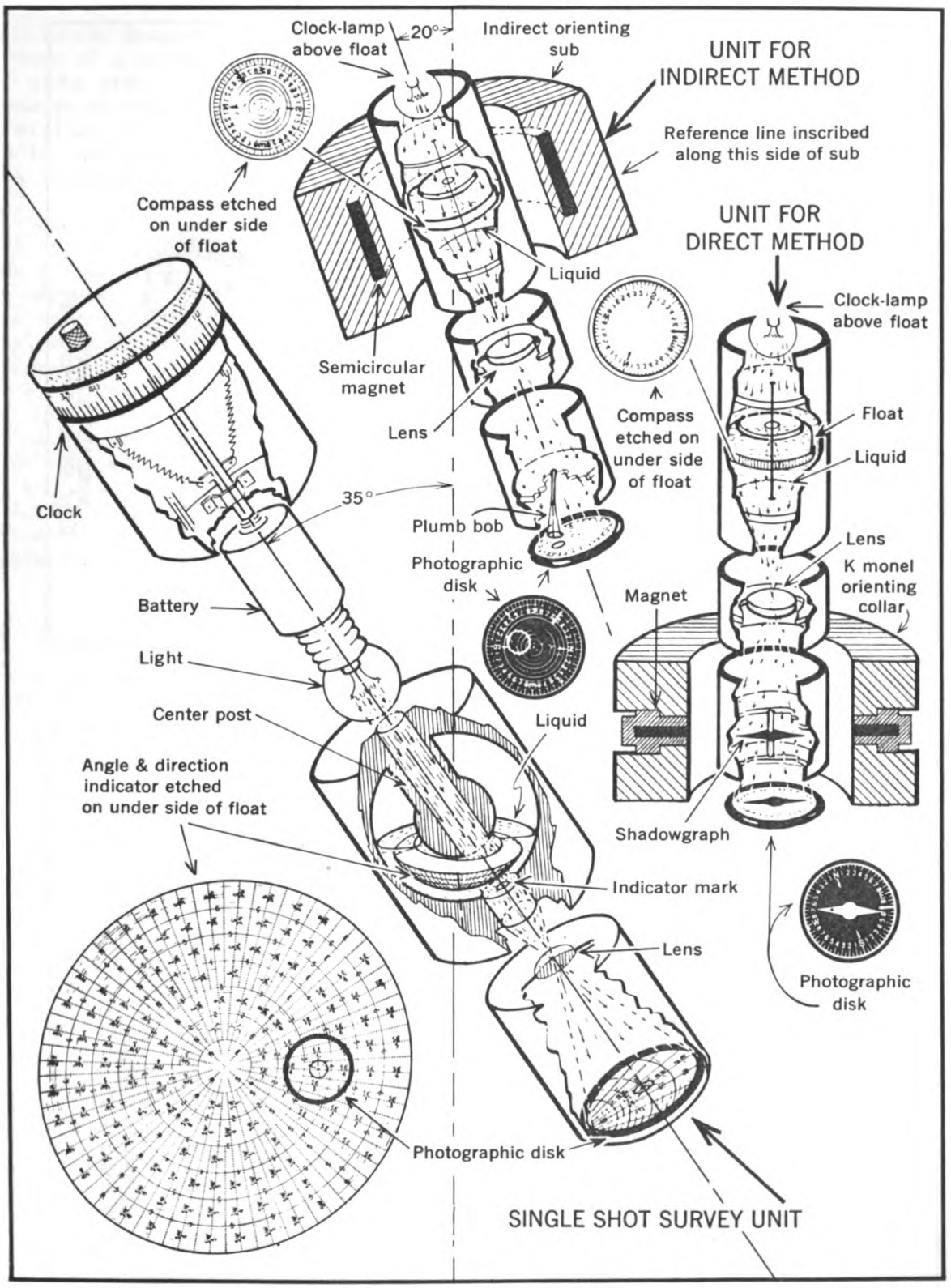

Figure 4. - Diagrammatic sections of survey units.

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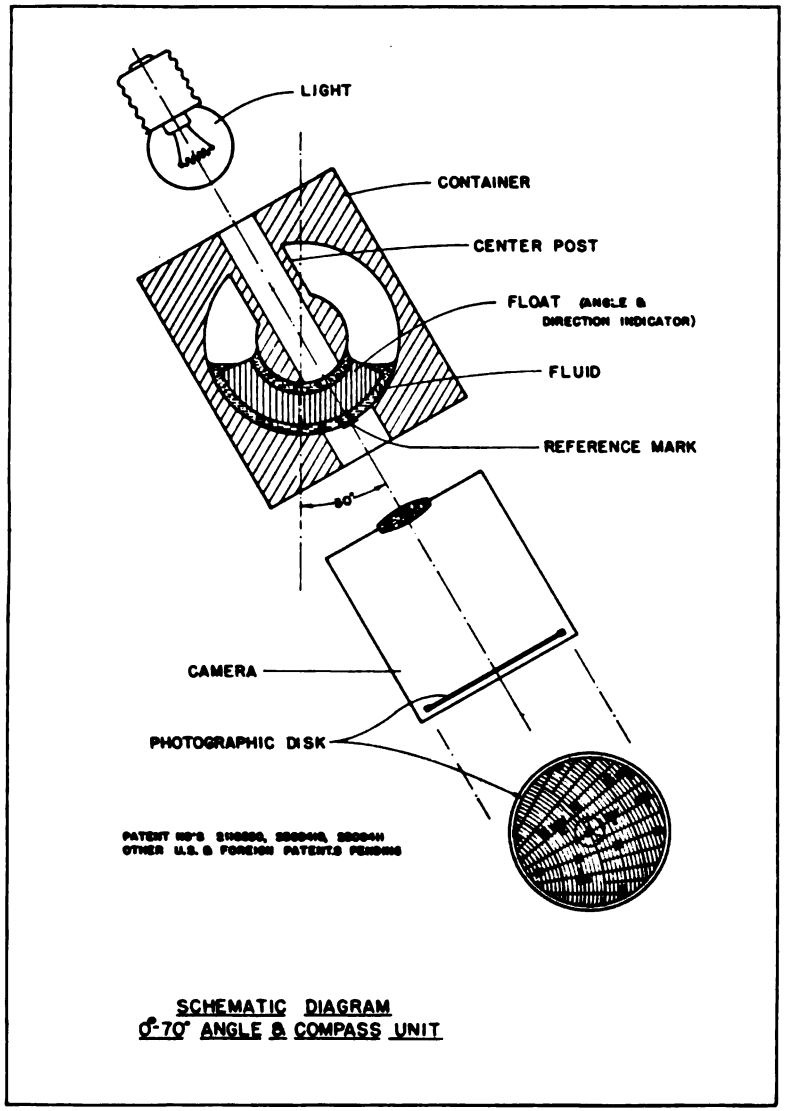

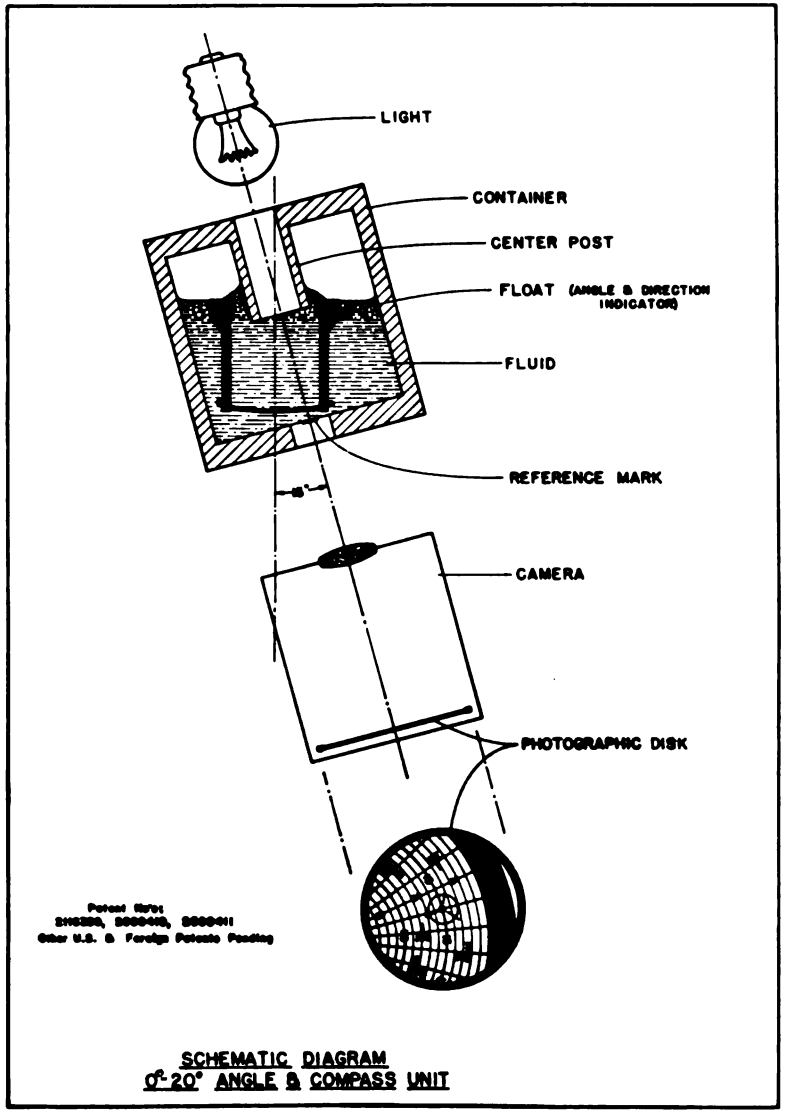

Figure 5. - Left, schematic diagram 0°–70° angle and compass unit; right, schematic diagram 0°–20° angle and compass unit.

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In the Homco-Kuster single-shot survey instrument and inclinometer, the float is made of a transparent material with lines of latitude and longitude engraved upon it, along with their respective degrees of angle. A reference mark is etched on a transparent section of the container and the center post has a transparent core with an electric bulb placed at one end as shown in figures 4 and 5. By means of a camera in the lower part of the unit, a photograph may be taken to record the reference mark in relation to the engraved surface of the float.

An enlarged view of the floating compass is shown in figure 6 along with the part of the float photographed by an H-K single-shot instrument. The lines of latitude represent the inclination of the container and the lines of longitude represent the direction of the inclination. The lower photograph on figure 6 is an actual size reproduction of an exposed disk; it is the permanent record of the survey. Thus, when the complete assembly is encased, lowered into a borehole and a picture is taken, the angle that the hole makes with the vertical and the direction of displacement from the vertical is read directly from the photograph.

A 0° - 20° Angle and Compass units (fig. 5) provide greater readability at the lower angles of inclination and are recommended for inclinations of 20° or less. The unit is similar to the 0° - 70° unit in basic operational principle, in that it employs a nonfriction, full-floating angle-direction indicator. The only difference between the 2 units is in their construction - the 0° - 20° unit is basically a floating plumb bob.

Orienting the Whipstock in the Drill Hole

After the whipstock is lowered into the drill hole to the depth at which it is desired to deflect the hole, the whipstock must be oriented in the direction in which the hole is to be deflected. There are 2 methods by which this may be accomplished: (1) The direct method, when the inclination of the hole off vertical does not exceed 12°; and (2) the indirect method, when the existing angle exceeds 12°.

Direct Method

In the nonmagnetic orienting collar (fig. 4, Unit for direct method) there are two small magnets. When the orienting collar, retrieving sub, and whipstock are made up on the derrick floor, the relative azimuth (compass degrees) position between the north attracting magnet in the orienting collar and the face of the deflecting tool is measured and noted. The whipstock is then run into the hole, and while circulation of mud fluid is stopped, the survey instrument is run into the hole on a wire line through the drill stem.

The survey instrument consists of a water-tight, light-tight metal case with a clock (fig. 4) in its upper end, which is set for a predetermined time to energize the light bulb and expose the sensitized paper disk in the lower section of the case. In the center of the case (fig. 3) go 1 of 3 interchangeable units (fig. 4):

1. Unit for direct method.
2. Unit for indirect method.
3. Single-shot survey unit.

The direct-method unit is a transparent nylon disk compass floating in liquid and a lens followed by the shadowgraph (magnetic needle). When the survey instrument has been lowered on a wire line down through the drill pipe to the whipstock, the instrument case seats on a collar so placed in the orienting collar that the

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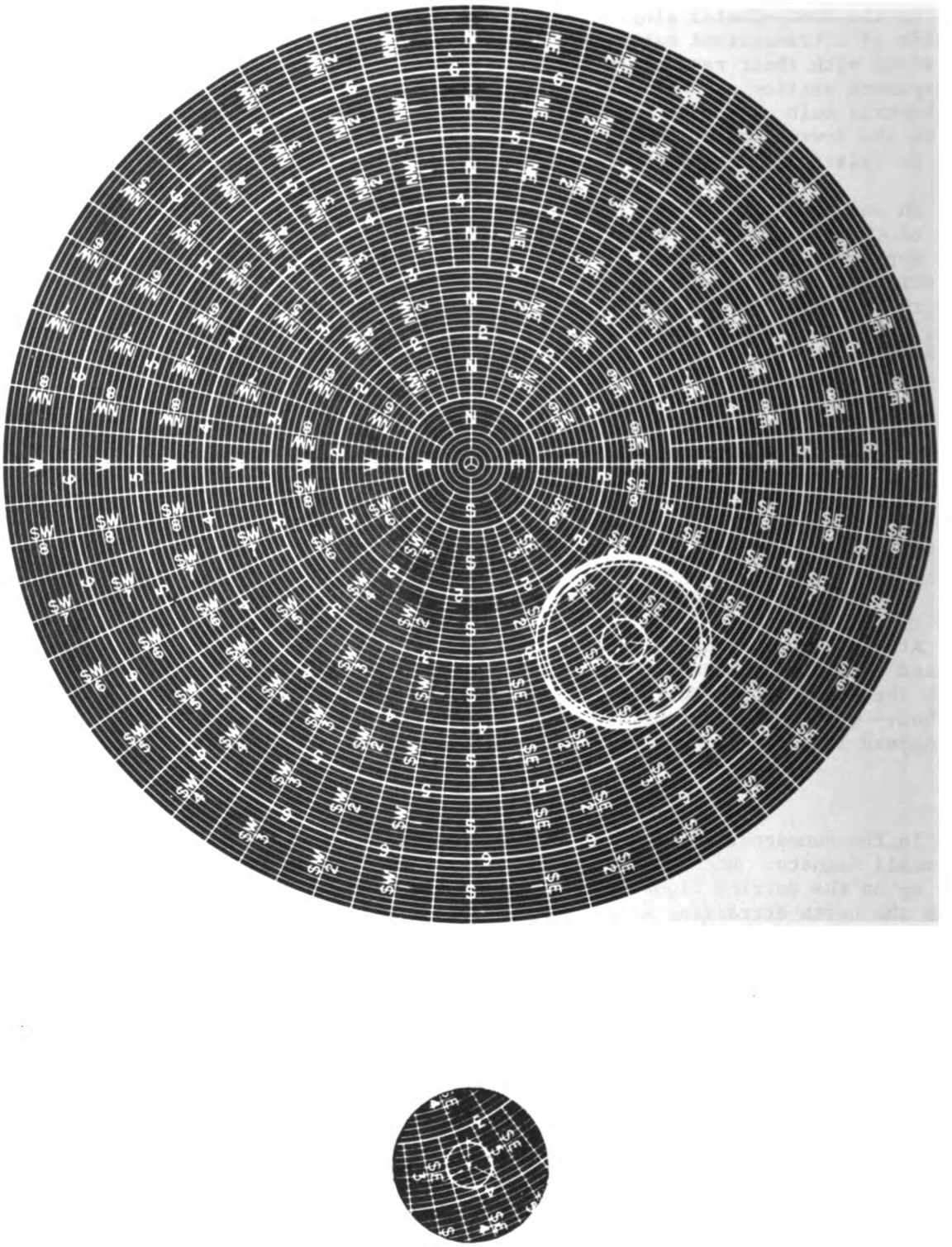

Figure 6. - Plan view of 0°–70° angle compass unit float with portion photographed.

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shadowgraph in the instrument will be exactly in a plane with the magnets in the orienting collar. The magnets lock the shadowgraph so that the black-dot-marked end of the needle points to the north magnet in the collar; thus the shadowgraph needle in the instrument gives a reference with relation to the face of the whipstock attached to the sub and collar. Meanwhile, the floating disk compass alines itself with the magnetic field of the earth. The clock has been set to allow ample time for the survey tool to be lowered and seated. The survey instrument is hoisted to the surface, and the film disk is transferred to the developing tank. Then from the film disk it can be readily determined which way the whipstock is facing and how many degrees to turn it in the desired direction.

The whipstock is then turned in the correct direction by rotating the drill column; weight is put on the drilling string to force the pointed end of the whipstock in the cement plug to secure the whipstock in position. Additional weight is then put on the drill stem to shear the pin that links the whipstock to the retrieving sub, thus freeing the bit and drilling string and permitting the bit, attached to the drill stem, to slide down the channeled face of the whipstock. The drill stem is then rotated and drilling the deflected hole is started.

Indirect Method

In the indirect method, the survey instrument is made up with the single-shot unit (fig. 4), previously described. All vertical holes tend to deviate from the vertical. To determine the bearing and inclination of the hole at the predetermined point of deflection, the survey instrument with the single-shot unit is lowered to this point, and a picture of the bearing and inclination is taken and recorded.

After the cement plug at the deflection point is set, the whipstock assembly is lowered in the drill hole, and the survey instrument containing the indirect unit (fig. 4) is run. This unit consists of a transparent floating disk compass, a lens, and a plumb bob hung by wire lines from the center of the unit. Below the plumb bob is the photo or film disk. For this survey the compass is so placed that with the instrument seated in the orienting sub of the whipstock assembly, the compass will be pulled with its north marking attracted to the north pole of the magnet in sub. The plumb bob is, of course, vertical. The timing device turns on the light, and the photo disk records the image of the plumb bob as it appears on the locked compass. By comparing the picture with the photo disk showing the direction which the more or less vertical hole slants (previously taken with the single shot instrument in the hole), the direction the whipstock is facing can be readily determined. The whipstock is then turned in the desired direction by rotating the drill column. Weight is then put on the drilling string to force the pointed end of the whipstock in the cement plug to secure it in position. The method of freeing the bit and drilling string is the same as the method previously described in the direct method.

Setting the Clock, Loading, Unloading, and Developing the Photo Disk

After the survey instrument is completely assembled, the clock is set to a predetermined time by completely depressing the pin or cap, depending on the type of clock, and turning the cap to the desired "time-until exposure" marking (fig. 7). A stopwatch is set to correspond to the setting of the instrument clock. The lower part of the instrument is the film disk holder, the knurled part of which should be turned until "open" is located opposite the arrow. The loader containing the film disk is placed on the instrument as shown in figure 8, and to insert the disk into the instrument, the slide of the loader is pulled out and then pushed in again. The knurled part of the film holder is then turned as far as possible and the loader removed from the instrument.

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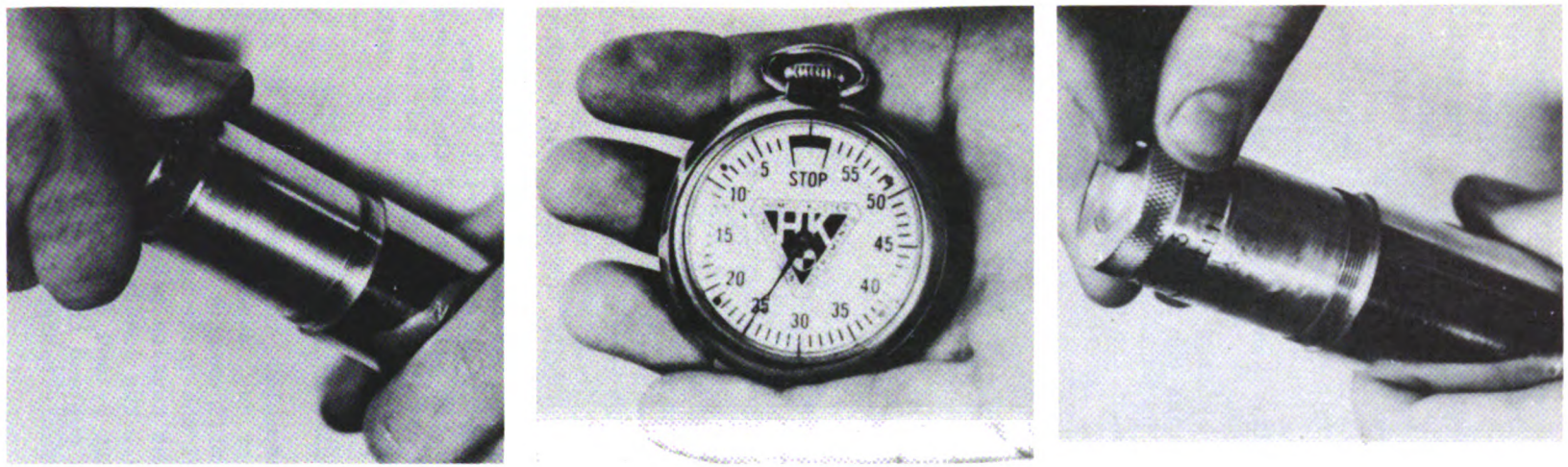

Figure 7. - Setting the clocks.

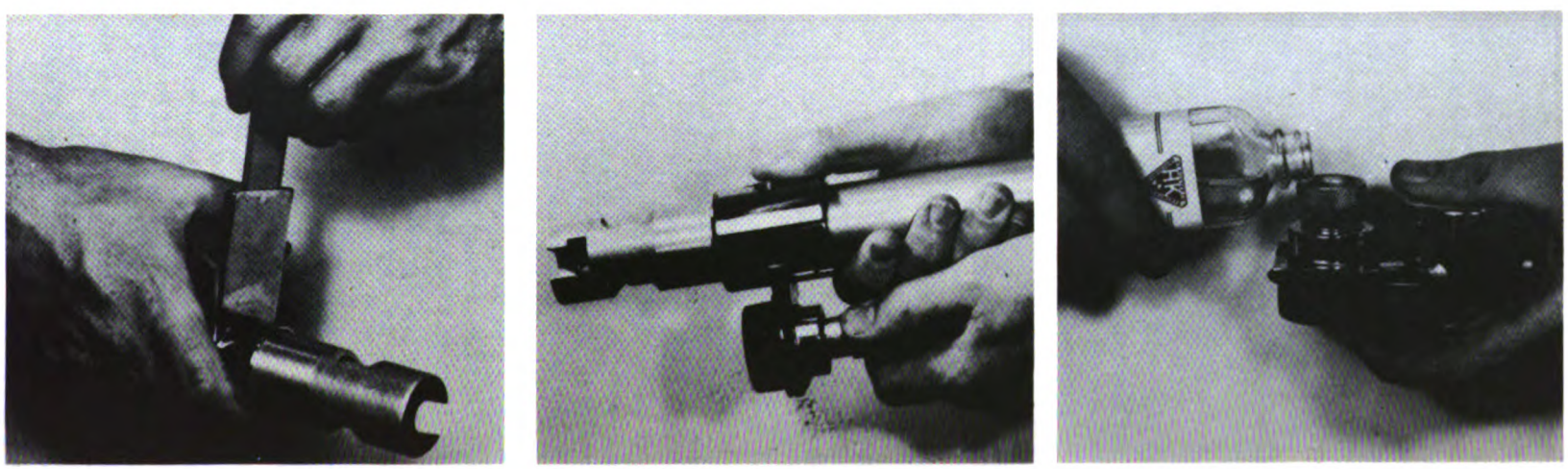

Figure 8. - Left to right, film disk loader, developing tank, and developing film disk.

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When removing the exposed film disk from the instrument, the developing tank is slipped over the end of the main frame. A light pressure on the spring will hold the developing tank in its proper position on the instrument (fig. 8). The knurled part of the film receiver is rotated until "open" appears opposite the arrow on the main frame. The knurled knob of the developing tank is now pulled out, the instrument shaken slightly and the knob released. Before removing the developing tank, the knurled knob of the film receiver is rotated back as far as it will go or until "empty" appears opposite the arrow to indicate that the disk has fallen into the developing tank. The developing tank is then removed from the frame.

The tank is held in the position shown in figure 8, and a combination developer and fixer is poured into the developing tank. The full tank is allowed to stand for about 4 minutes before the film is removed, rinsed with fresh water, and dried. The film shows the bearing and dip of the hole and is a permanent record of the survey.

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